Foundation Engineering

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Module - 02
Lecture - 11
Pile Foundations - 6

Hello viewers, good evening to all of you, in the last class, we were we started the dynamic pile load formulae. In that one, we started with two formulas that, one was engineering news formula and another was modified Haley formula.

We saw in detail, what were the salient features of the engineering news formula, then we saw that being simple in nature. It is accepted worldwide and gives reasonably values as far as the allowable load on the pile are concerned, then we started with that how you can find out the allowable load using modified Haley formula. Let us start with the same and see that what exactly is that formula and what are the other parameters in that particular formula.

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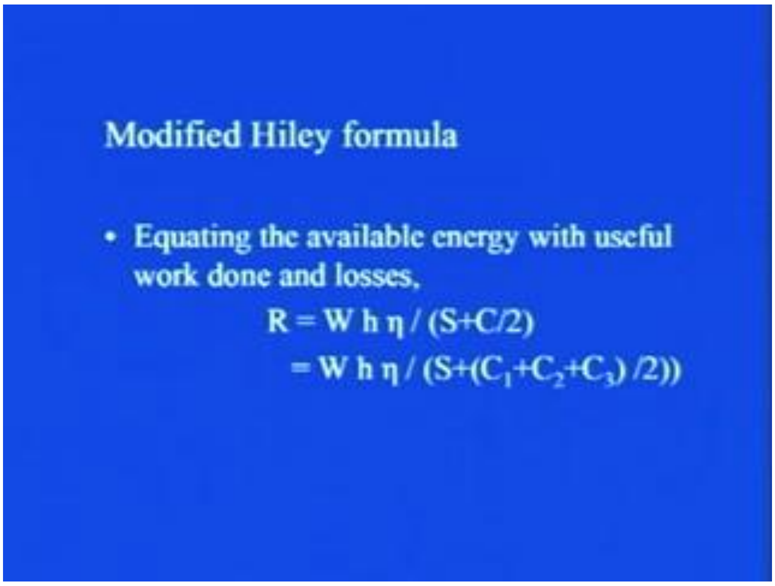

As, we have already seen that by equating the available energy with useful work done and the losses this are which is your ultimate resistance that becomes equal to W h eta by s plus C 1 plus C 2 plus plus c 3 by 2.

And in the last class, we saw that if you divide this R by a factor of safety of 2.5 you get the allowable load on the pile. This W was the weight of the hammer and eta we saw was the efficiency which has to be provided by the manufacture.

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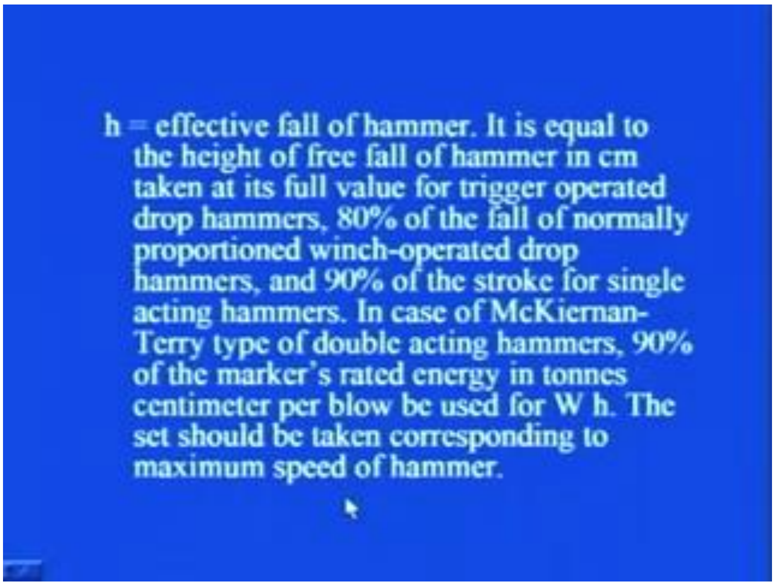

Now, lets us try to see that, what exactly are the other parameters used in this particular formula. First come, let us come to h you can see here that it is effective fall of hammer, so depending on, what type of hammer that, you are using for driving the pile, this effective fall will be different. So, this again will also be provided to you by the manufacturer, however you must be familiar with some of the mechanical terms, let us not go into detail of all those mechanical terms.

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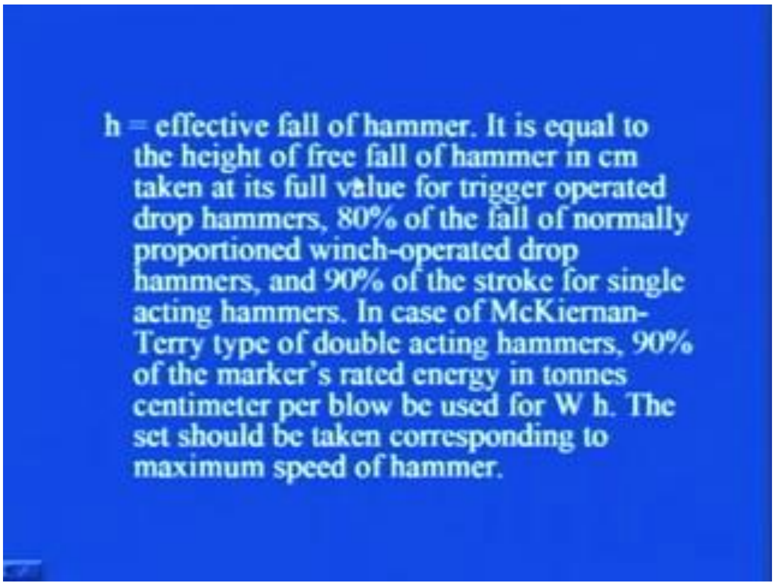

But you should know that, what are those terms, so for that purpose this h is equal to the height of free fall of hammer in centimeter taken at it is full value for trigger operated drop hammers. However 80 percent of the fall of normally proportion winch operated drop hammers and 90 percent of the stroke for single acting hammers. In case of McKiernan Terry type of double acting hammers 90 percent of the marker's rated energy in tones, centimeter per blow be used for W into h. The set should be taken corresponding to maximum speed of hammer.

So, once I read out all these material which is written in this particular slide, you can see that most of the terms they are related to the machine that which type of machine that you are using, what type of hammer that, you are using so you do not have to worry for this particular parameter, because it has to be provided to you by the manufacturer only. But nevertheless, you must know that was exactly it is meant by.

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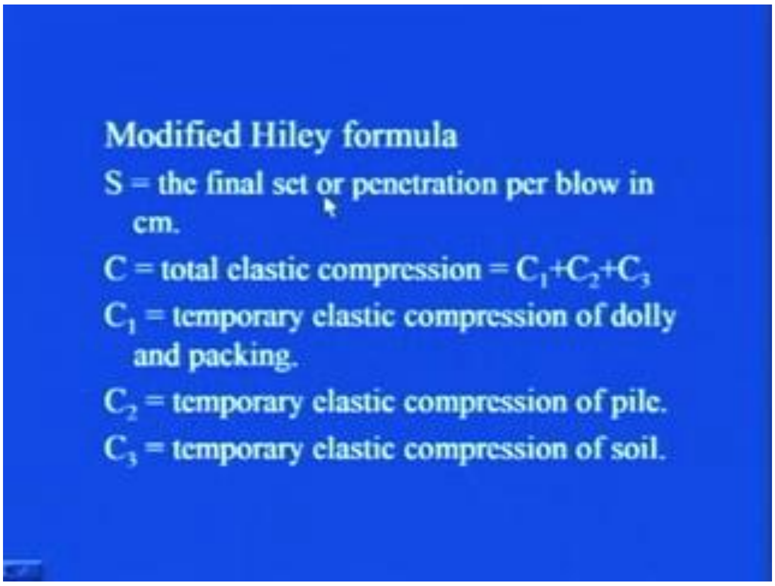

Further, S is the final set or penetration per blow in centimeters C I told you that you have to be very careful about that, what exactly is the unit, that you are using while you are using these dynamic formula, because many times you are when you are taking into account the losses in the energy.

So you are introducing empirical factors, so you have to be consistent with the units. C is the total elastic compression which is equal to C 1 plus C 2 plus c 3 where C 1 is temporary elastic compression of dolly and packing. You have to make some arrangement when you go for hammering, so the arrangement about the pile they it is this dolly and packing etcetera.

Then, C 2 is the temporary elastic compression of pile, C 3 is temporary elastic compression of soil. So, these are the three terms where this apart from the vertical settlement of the pile, these three will be the terms which will be taking a part or which will be imparting to that particular settlement. So, these have to be taken care off.

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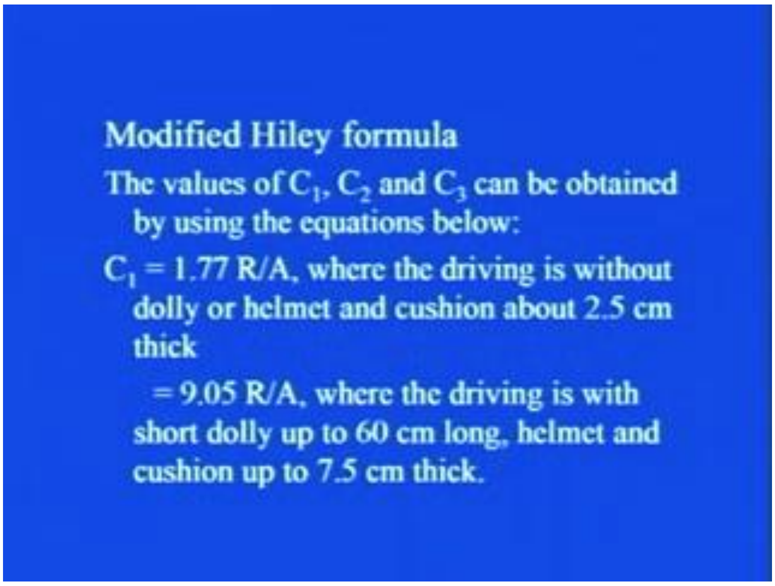

Now, how to estimate these values or these parameters, some guidelines have been given. The values of C 1 C 2 and C 3 can be obtained by using the equations which are given in this particular slide and then subsequent slides, C 1 is 1.77 R by A, where the driving is without dolly or helmet and cushion about 2.5 centimeter thick is used.

And in another case, it is 9.05 times R by A, where the driving is with short dolly up to 60 centimeter long helmet and cushion up to 7.5 centimeter thick. So, whatever is the arrangement that you are making while driving the pile using this any of the dynamic method depending on that. You have to pick this value of C 1 either using this expression or using this particular expression.

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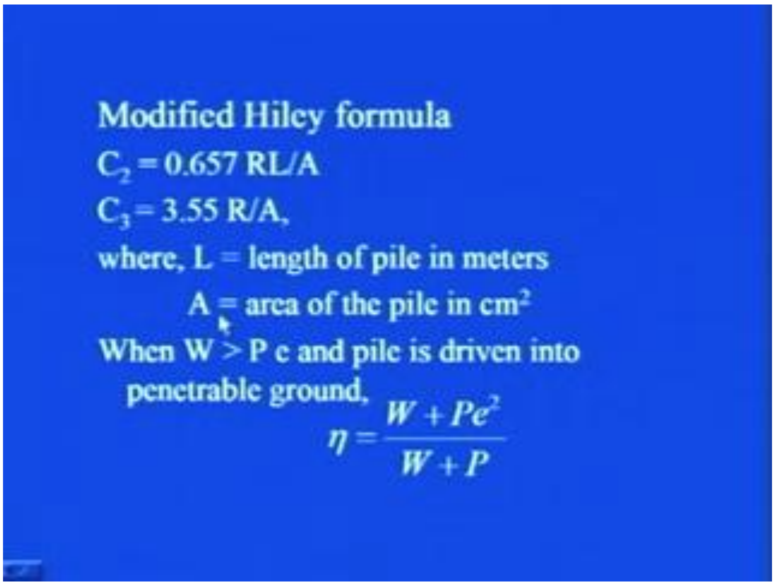

Then, C 2 is 0.657 R L by A, c 3 is 3.55 R by A, where L is length of pile in meters, A is area of the pile in centimeter square. So, R is in tones, so L is in meters, where as I am using this area in centimeter, so you have to be very careful about the units of respective parameters, because these are empirical expressions. So, these differences in the unit they have been taken care of while deciding upon this particular empirical factor.

So, when your W is more than P e and the pile is driven into penetrable ground your, eta will become w plus P e square by W plus P, so that here eta I define that it is ratio of this quantity and this quantity. So in case, your W is more than P e, then eta can be found out using this particular expression.

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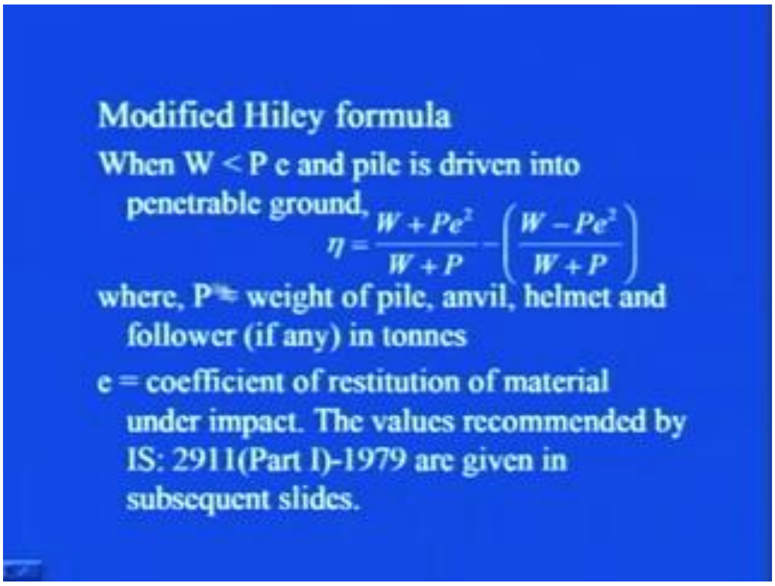

However, when W is less than P into e then and the pile is driven into penetrable ground, then your eta becomes w plus P e square by W plus P minus W minus P e square by W plus P, where your P is weight of pile anvil helmet and follower if any in tones. So, whatever is the assembly that you are using for driving the pile using hammering the this p comprise of weight of all those this terms.

So, e is your coefficient of restitution of material under impact, then how to evaluate this value of e, again some guidelines have been given in Indian code that is IS 2911 part 1979 and what are they.

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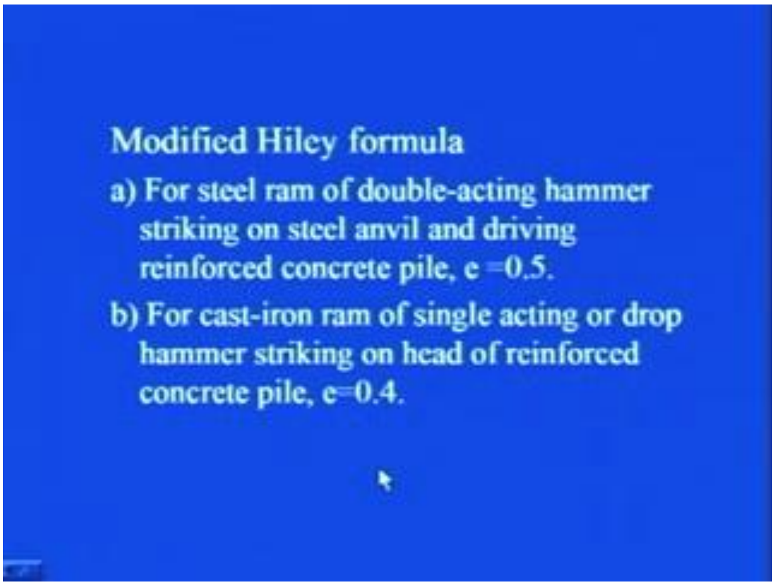

Let us try to see 1 by 1, again this is related to that, what type of hammer that you are using, I am simply not going into detail of all this, because that will lead into another subject all together different one. But, for the sake of finding out the allowable load on the pile using this dynamic formula, what exactly is that formula, what are the various terms, which are coming into that particular formula. And then, from where you can get an appropriate value of these parameters be it is code guideline or some other study.

So, for steel ram of double-acting hammer striking on steel anvil and driving reinforced concrete pile e value you can take equal to 0.5. Then for cast-iron ram of single acting or drop hammer is striking on head of reinforced concrete pile e you can take 0.4. So, depending on what exactly is the type of hammer that you are using for driving the pile into the ground, you have to pick corresponding value of this coefficient of restitution e as per IS code.

Further, for single acting or drop hammer is striking a well conditioned driving cap and helmet with hard wood dolly, while driving reinforced concrete piles or directly on head of timber pile e value you can take to be equal to 0.25. Then, fourth case is for a deteriorated condition of the head of pile or of dolly e, you have to considered to the equal to 0. So, depending on what exactly is the condition, what type of pile that you are driving, what is the arrangement that you have made, you can choose the corresponding value of e.

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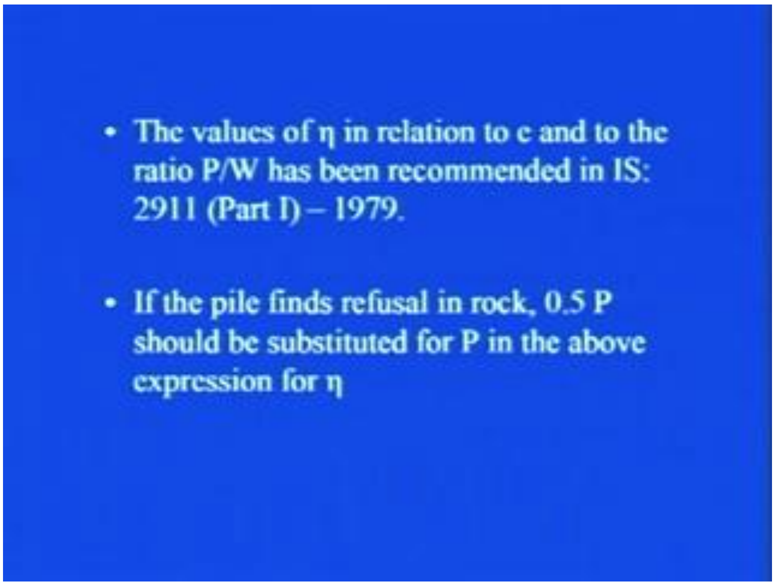

The value of eta in relation to e and to the ratio P by W has been recommended in IS 2911 part I 1979. So, you have to simply pick this particular code and see the corresponding value that what exactly is the assembly, what exactly is the type of this efficiency and all that you are using and correspondingly to those particular conditions you can pick the value of this eta.

If the pile finds refusal in rock 0.5 times p should be substituted for P in the above expression for eta. So, whatever is the expression that has been used, in IS 2911 in case the pile is finding refusal in rock, you simply have to substitute 0.5 times P in place of pi; that means, it you have to reduce the value of P, which is the weight of anvil helmet dolly and all other arrangements by 50 percent and then you can go ahead for determination of this value of eta as per IS code.

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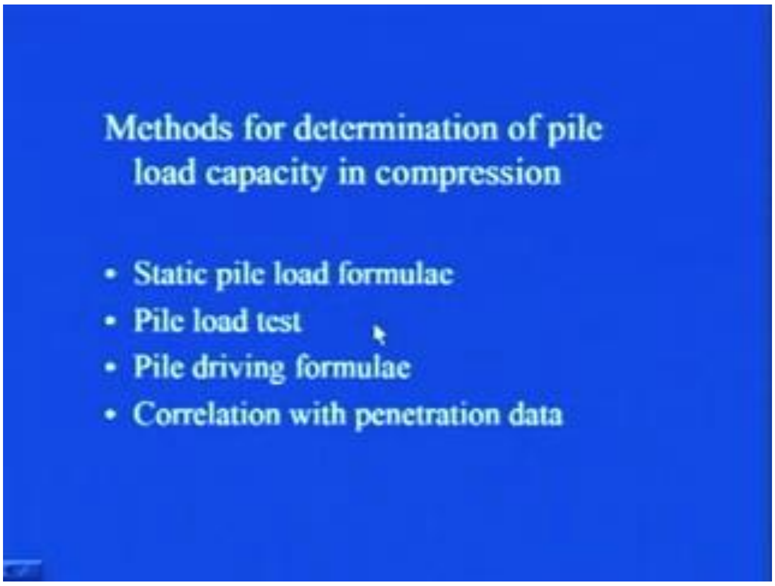

Then, this was all about that, how you can use this pile driving formula or dynamic pile formula, as far as computing or estimating allowable load on the piles is concerned. Now, after that let us start with the fourth and the last one that is correlation with penetration data. Various research workers over the years from their experience from engineering judgment they have worked out that, what exactly should be the relation in allowable load capacity or ultimate load capacity of the pile, to the standard penetration test data.

Because, it usually it is easy to get standard penetration test data at any particular site when you go for soil exploration. So, to get a rough idea about that what can be the load capacity of the pile just to get the rough and quick idea about that, you can use these correlations with penetration data, what are these, because depending on that, what exactly is the type of the soil, what is the method of installing of the pile, depending on all these factors. These empirical relations which have been developed they differ from one to another.

It is not necessary that a particular expression which is suitable are giving you very reasonable value at one particular site will give you equally reasonable and good value at another site also it is not necessary. So, you have to judge that, which one would, you like to use, which one you should use as far as the load capacity of the pile is concerned.

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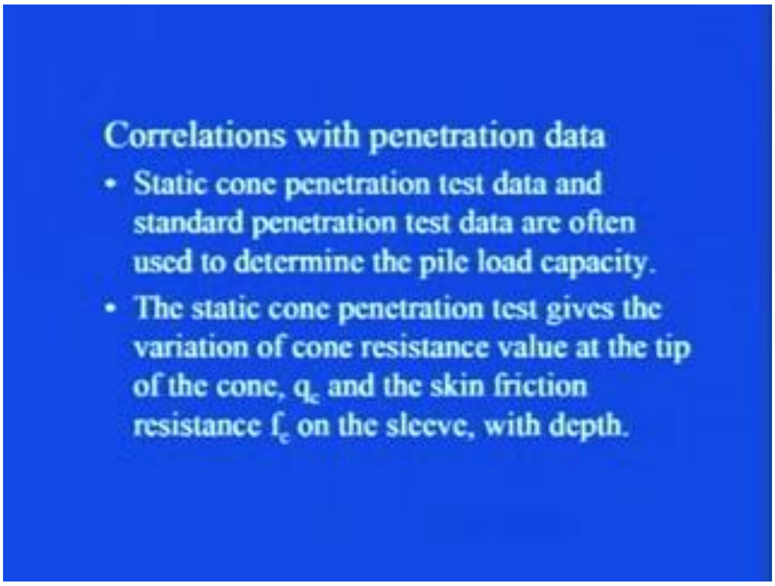

So, static cone penetration test data and standard penetration test data are often used to determine, the pile load capacity. When you were studying that soil exploration chapter there you might have must have studied, these two test and what are the various specifications of these test, that is the standard cone penetration test and standard penetration test. So, from the result of these two tests, you can estimate the pile load capacity.

The static cone penetration test gives the variation of cone resistance value at the tip of the cone which is q c and the skin friction resistance f c on the sleeve with depth. I hope that you this, but for the sake of completion and continuity in the particular lecture, just I have mentioned that what exactly do you get out of this static cone penetration test. This gives you the variation of cone resistance value at the tip of the cone which I call as q c and the skin friction f c which is on the sleeve with respect to depth.

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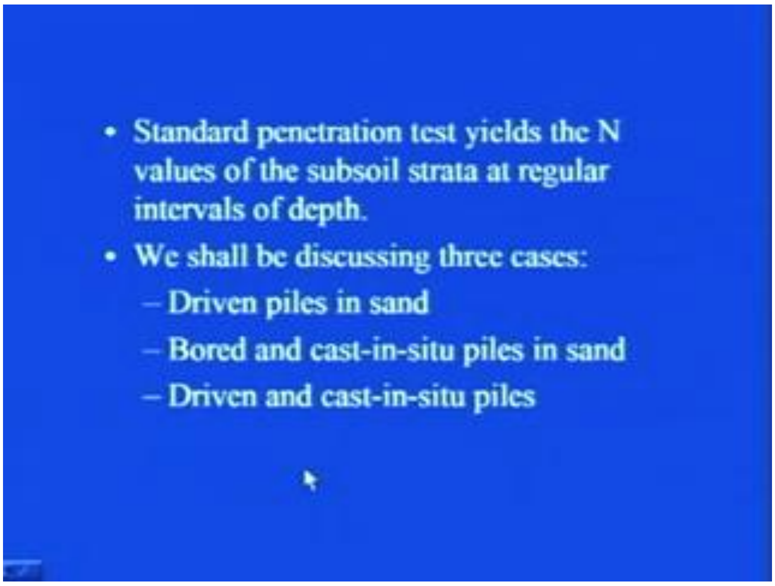

However, this standard penetration test yields the N value for the sub soil strata at regular intervals at depth. So, end value also at depth at any particular depth you can obtain using standard penetration test data.

So, we shall be discussing here, mainly the three cases that, how you can estimate, the pile carrying load carrying capacity using this correlations with penetration test data. In case driven piles in sand, Bored and Cast-in-situ piles in sand and then third one is Driven and cast-in-situ piles.

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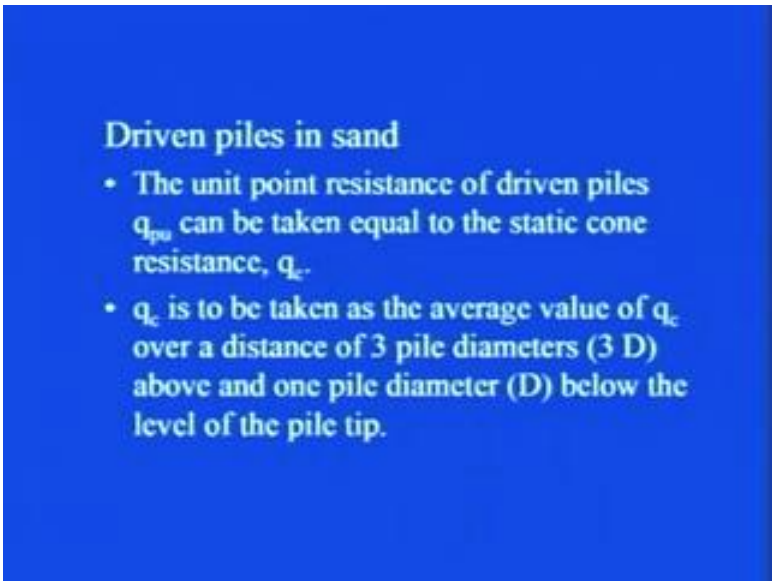

Let us see 1 by 1, first is driven piles in sand. The unit point resistance of driven piles that is q pu can be taken equal to the static cone resistance q c. So, you the data from static cone penetration test and standard penetration test also, so as far as the driven piles in sand are concerned.

The unique point resistance of driven piles, because you know that to know the allowable load or the ultimate load carrying capacity of the pile, you need to have the ultimate point bearing resistance plus ultimate skin friction resistance. So, in case of this driven piles in sand this unique point resistance of driven pile can be directly taken to be equal to q c.

q c is to be taken as the average value of q c over a distance of 3 pile diameters that is 3 D above and one pile diameter D below the level of the pile tip. So, wherever you are considering at any particular depth that q c that you are finding out that is point bearing resistance. So, since this q c you get as per the depth at different different depths you have got the different values of q c. So, how you can find out, because this q pu you require at the base of the pile tip.

So, the average value of q c that you must take into account is that below the base of the file tip. D distance that is the equal to this pile diameter and along the pile shaft data above the base of the pile to be at a over a distance of 3 pile diameters. You have to take the average value of this q c over this particular length of the pile, to know the average value of q c to find out this q pu.

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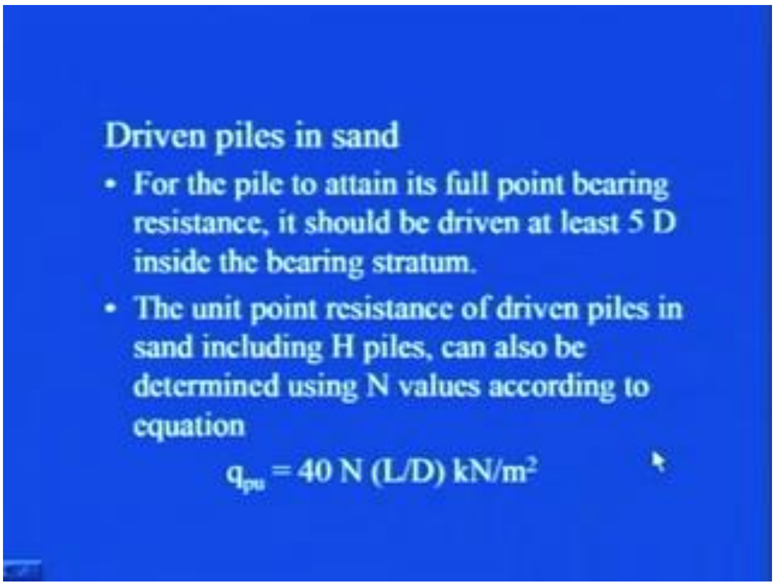

For the pile, to attain its full point bearing resistance it should be driven at least 5 D times inside the bearing stratum.

So, as you know that, why we go for pile foundation, wherever there is no availability of good soil strata at the shallow depth, then we go for the deep foundation and pile foundation is one of that types. So, wherever you get the hum good strata there at least you the pile should be driven at least to 5 times inside that the bearing stratum, to get the full point bearing resistance. If it is less than that; obviously, whatever is the full point bearing resistance that you can get from that particular pile that you will not be getting.

The unit point resistance of driven piles in sand, including H piles, I hope that you remember that, what exactly is that, H pile this is or having H cross section made up of steel, it can also be determined using n values according to equation q pu is equal to 40 N L by D kilo Newton per meter square.

See these are all empirical correlations, so again here in this case also you have to be very careful about the units that you are using. So, in this case earlier we were talking with respect to static cone penetration test data; however, in this case including this H pile the unit point resistance of driven piles in sand can be estimated using this particular expression, where N is the standard penetration number that you can get from standard penetration test data, L is the length of the pile and d is the diameter of the pile.

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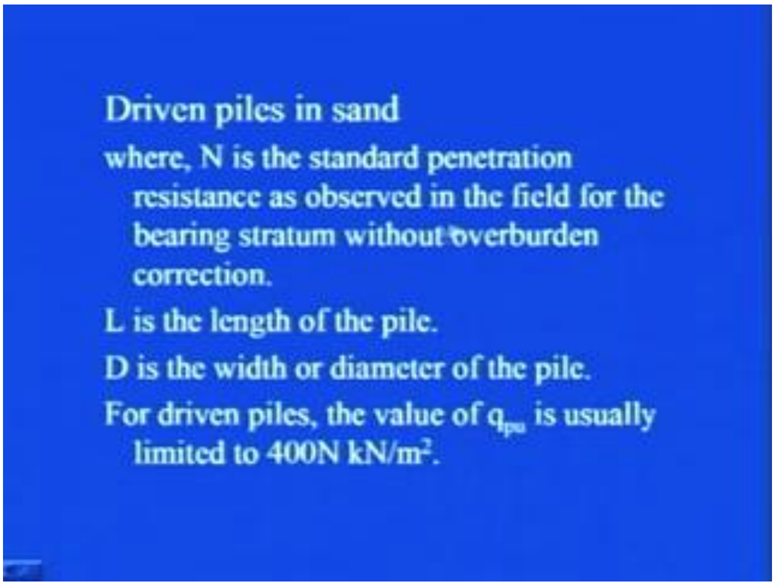

Where, N is the standard penetration resistance as observed in the field for bearing stratum without over burden correction.

You know that, once you get from the n value from the field and if there is clay you do not apply any correction. But, if the sand is there which we are talking here in this case, so this n value you have to use n uncorrected, you do not have to correct it for over burden. So, directly that value that you must take here in this particular expression, L is the length of pile d is the width in case of square or rectangular pile and diameter in case of circular pile.

For driven piles the value of q, q pu is usually limited to four hundred n kilo Newton per meter square. So, you can find out the value of q pu from this particular expression and from this expression also that is q pu is equal to 400 N, so if that value is that is this value from this particular expression. If it is working out to be more than this particular value, then you have to restrict this value that is q pu value to this particular value that is to the maximum of this 400 N, it can bear that is as point bearing resistance.

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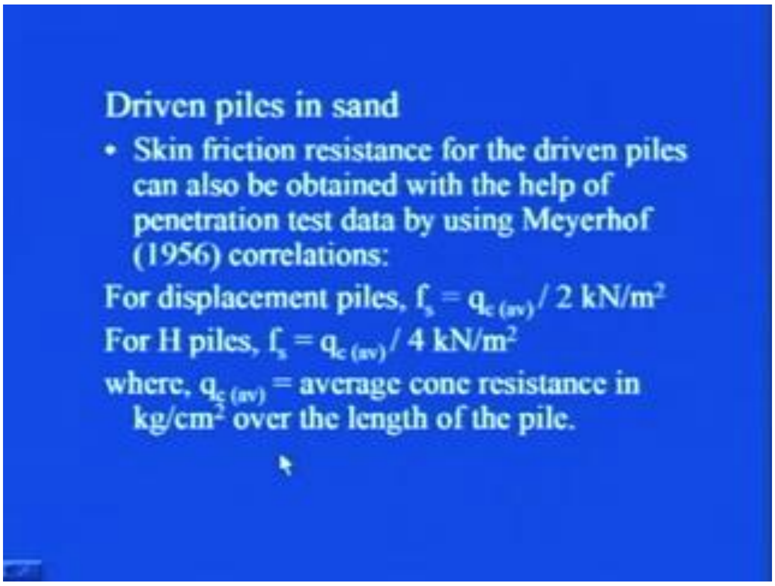

Now, let us see that how skin friction resistance can be obtained using the various correlations. Skin friction resistance for the driven piles can also be obtained with the help of penetration data by using Meyerhof's correlations which he gave in 1956. So, he says that for displacement piles f is equal to qc average divided by 2 kilo Newton per meter square.

You know that what do you mean by displacement piles and non displacement piles, we have discussed it in very first lecture related to pile foundation. However in case of H piles H, in case you are using H piles this f s, becomes qc average divide by 4 for displacement pile it was 2 divided by 2 and; however, in case of H piles it is divided by 4.

Where this q c average is average cone resistance in kg per square centimeter over the length of the pile, this is kg per square centimeter. However, you are getting the value of this skin friction resistance in kilo Newton per meter square. So, you have to be really very careful about the units, because these are empirical correlations.

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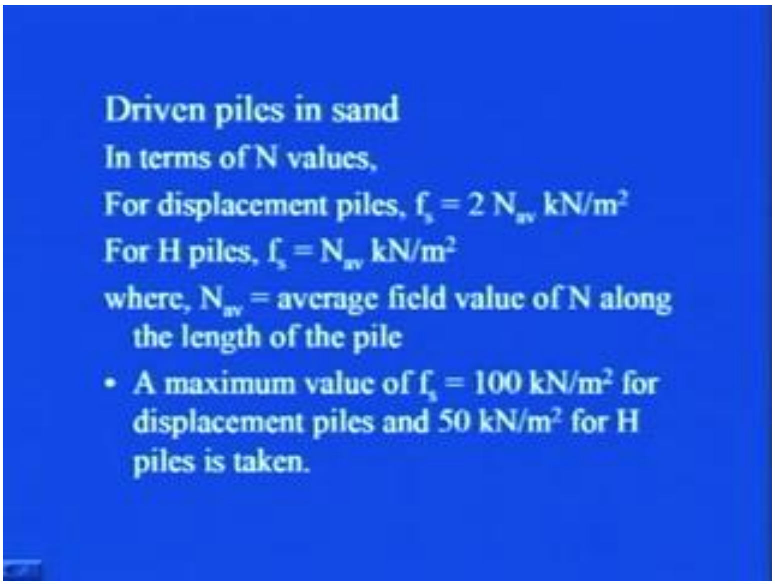

In terms of N values, for displacement piles your f s is become equal to 2 times N average kilo Newton per meter square. However, for h piles this f s becomes equal to N average kilo Newton per meter square, where N average is average field value of N along the length of pile.

In case, as it was there in case of point bearing in case of skin friction resistance also, you have some limiting value that is a maximum value of f s is equal to 100 kilo Newton per meter square for displacement piles and 50 kilo Newton per meter square for h piles is usually taken.

So, you have whenever you are finding out point bearing resistance or skin friction resistance. You have to keep a check that those particular values which you are calculating from an empirical formula that you should not exceed the limit which have been specified by different research workers from their experience and engineering judgment point of view.

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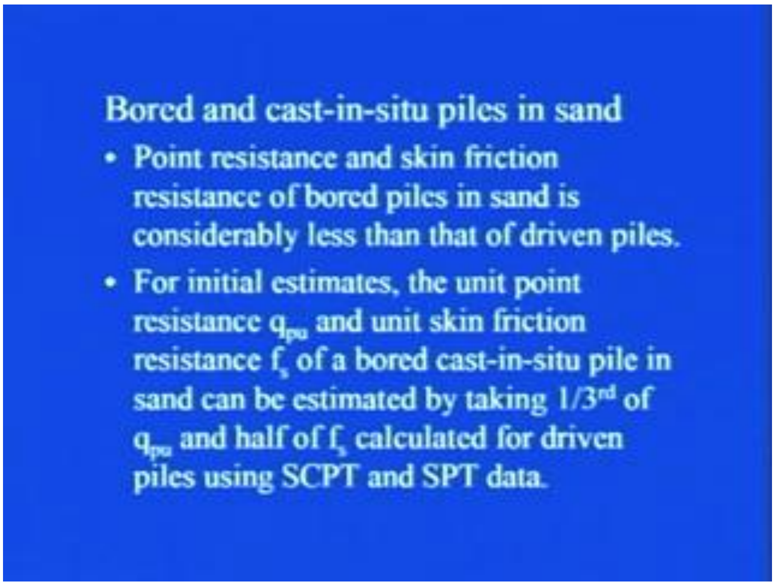

Then, let us start with the second type that is bored and cast-in-situ piles in sand. Just now we were discussing all about, driven piles in sand, now it is bored and cast-in-situ piles in sand.

In this case point resistance and skin friction resistance in sand, is considerably less than that of driven piles. As, this aspect we have already seen that, why exactly it happens that, in driven piles the passive condition get mobilized and so you get that coefficient of lateral earth pressure in passive condition and which results in higher values of point resistance and skin friction resistance as compared to the bored piles.

For initial estimates, the unit point resistance q pu and unit skin friction resistance q s f s of a bored cast-in-situ pile in sand can be estimated by taking one-third of q pu and half of f s calculated for driven piles using SCPT and SPT data. You have seen that using a standard cone penetration data you can estimate the point bearing resistance at its unit point resistance q pu in case of driven piles in sand.

And, you have the all those expressions with you, so to get the rough estimate of q pu that is unit point bearing resistance in case of bored and cast-in-situ piles in sand. Roughly, if you divide the value corresponding in case of driven piles in sand by 3, then roughly that will give you the value in case of bored and cast-in-situ piles in sand.

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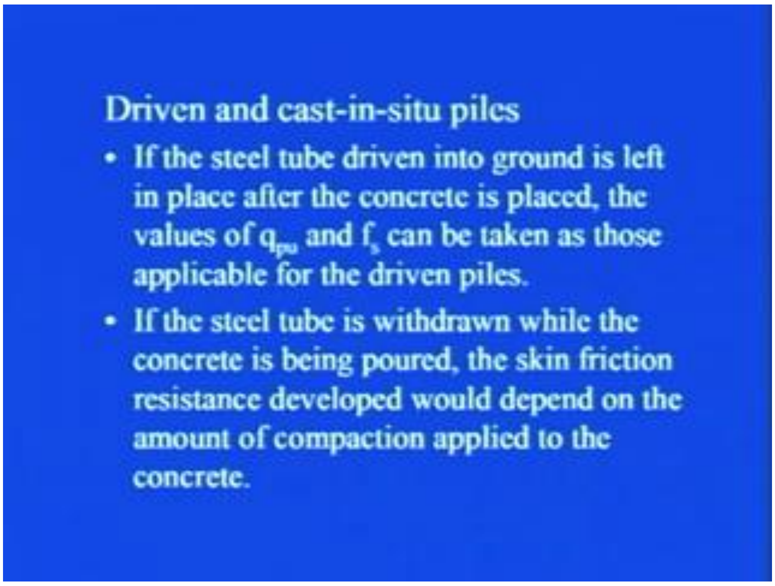

If the is steel tube driven into ground is left in place after the concrete is placed, the value of q pu and f s can be taken as those applicable for the driven piles. That means, that in case of cased piles you remember that I told you that in this is, what is in case of driven and cast-in-situ piles. So, while driving if the steel tube has been driven into the ground has been left at its place. Then, whatever is the value of driven pile that you got in the first case, you can use simply and confidently in case of driven and cast-in-situ piles.

Now, if the steel tube is withdrawn while the concrete is being poured, the skin friction resistance developed would depend on the amount of compaction applied to concrete. This aspect we also studied when we were studying the details about driven and cast-in-situ piles and their behavior in different type of soils.

So, in case the steel tube is getting withdrawn see, when the steel tube on the casing tube is in its position and the concreting is done and the steel tube is left as it is in position. What happens is that concrete is confined in that particular tube, whatever is the degree of compaction that you are imparting, it is all together taken by the concrete only.

But, in case if you are taking that casing out, then the degree of compaction becomes an important parameter to decide upon on the further analysis and design of the pile. So, that is what is being stated here that the amount of compaction which has been applied to the concrete will play an important role. In case the steel tube is withdrawn while concreting is done.

Two cases can be there, in one case the proper concreting has been done, in another case the proper concreting or the compaction during concreting has not been done.

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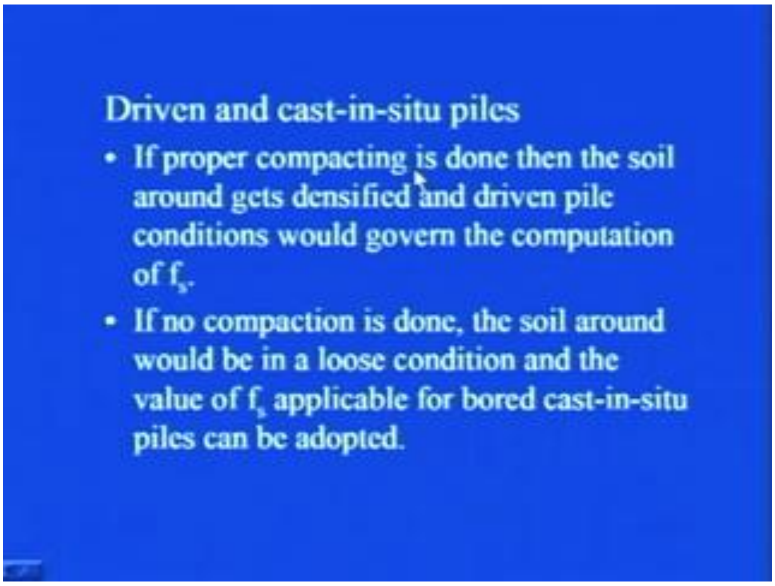

So, in case the proper compacting is done, then the soil around gets densified and driven pile condition would govern the computation of f s. So, you see when you drive the pile, due to the mechanical hammering or driving procedure, what happens is the soil around that particular pile gets compacted, so if the compacting of the concreting has been done properly. Exactly the same situation, arise in this particular case and that is why the driven pile condition will be governing the computation of f s. In case no compaction is done, the soil around would be in a loose condition and the value of f s applicable for bored cast-in-situ pile can be adopted.

Because, in while you go for bored cast-in-situ pile first you create a void or bore hole into the ground and then you fill it with concrete. So, in the process of creating that bore hole, the soil at the wall of the bore hole releases it is stress and so it gets loosen. In that case if the compaction has not been done properly, the soil will be in loose condition and which will represent the bored cast-in-situ pile situation.

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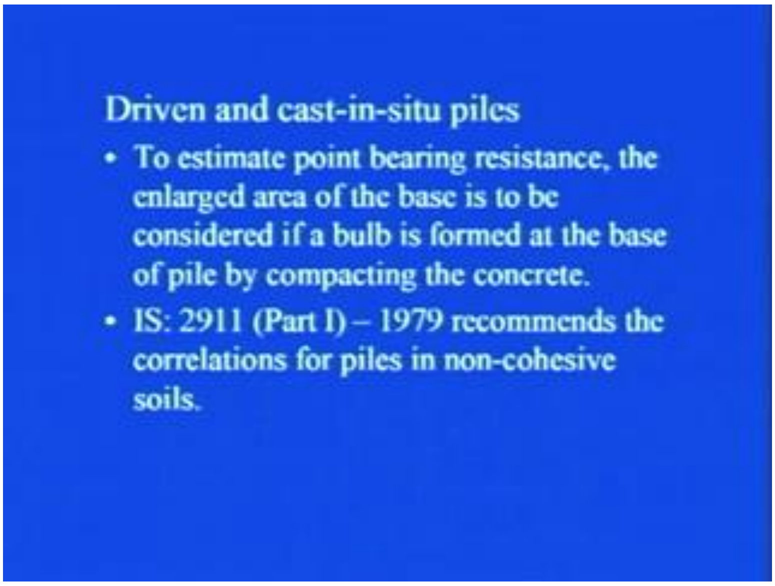

Then, in case of driven cast-in-situ pile, to estimate point bearing resistance the enlarged area of base is to be considered, if a bulb is formed at the base of pile, by compacting the concrete. Now, in; obviously, if a bulb is there at the base that will give you more point bearing resistance and you must take into account that particular aspect. Then IS 2911 part I 1979 recommends the correlations for pile in non-cohesive soil.

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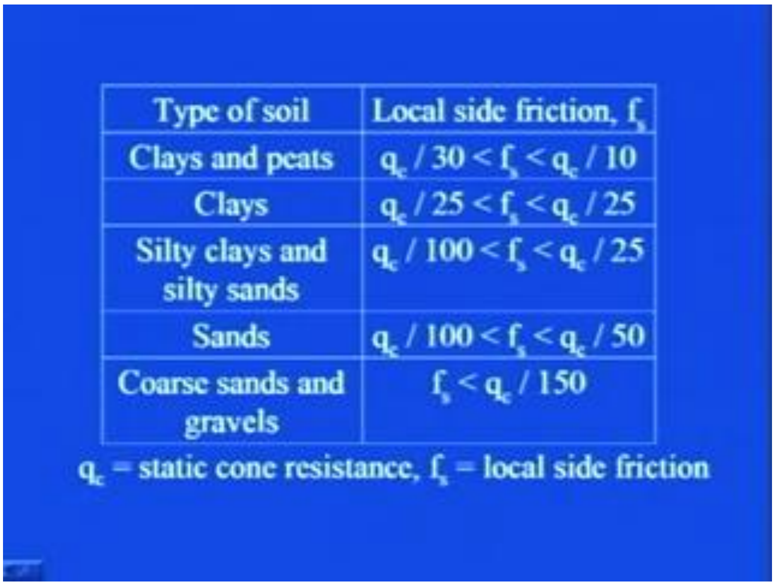

Type of soil	Local side friction, f_s
Clays and peats	$q_c / 30 < f_s < q_c / 10$
Clays	$q_c / 25 < f_s < q_c / 25$
Silty clays and silty sands	$q_c / 100 < f_s < q_c / 25$
Sands	$q_c / 100 < f_s < q_c / 50$
Coarse sands and gravels	$f_s < q_c / 150$

q_c = static cone resistance, f_s = local side friction

What are they, you can have a look here in this particular table, this I have taken from IS code only. So, depending on the type of the soil different expressions or different limits for local site friction f s has been given, that is if the pile has been driven in clays and peats. Then, the upper limit of this f s that is local site friction is qc by 30 where qc is the cone penetration resistance that you are getting from static cone penetration test data.

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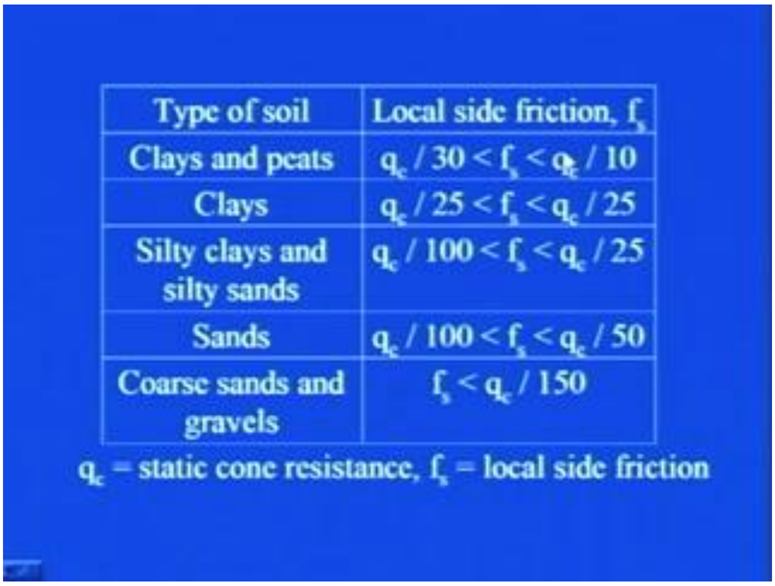

Type of soil	Local side friction, f_s
Clays and peats	$q_c / 30 < f_s < q_c / 10$
Clays	$q_c / 25 < f_s < q_c / 25$
Silty clays and silty sands	$q_c / 100 < f_s < q_c / 25$
Sands	$q_c / 100 < f_s < q_c / 50$
Coarse sands and gravels	$f_s < q_c / 150$

q_c = static cone resistance, f_s = local side friction

And it is this limit high limit is qc by 10, so that f s must lie between qc by 30 to qc by 10. In case of clays, it is qc by 25; that means, I think it is qc by 25 only. Silty clays and silty sands that is q c by 100 to qc by 25, in case of sands that is qc by 100 to qc by 50. Then, coarse sands and gravels it is that fs should be less than your qc by 150.

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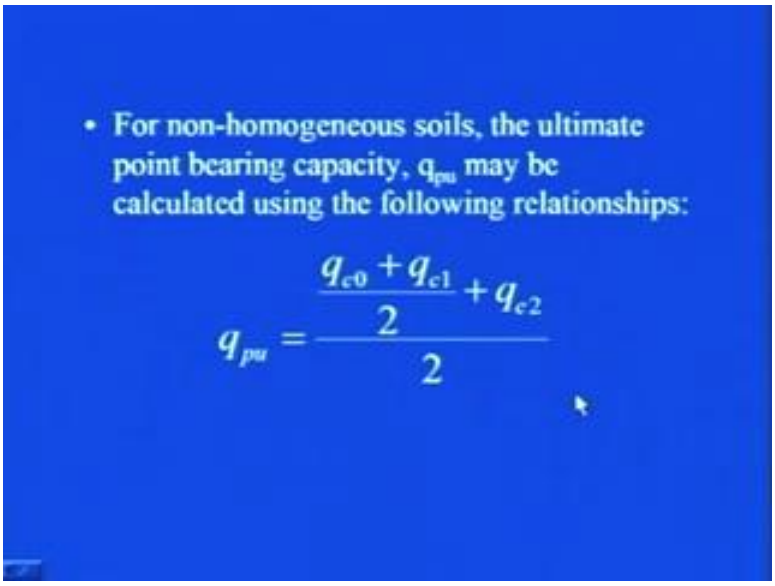

So, q c you can get from static cone penetration test data and depending on that you have the two limits for different type of soil and you can pick the corresponding values, what happens in case of non-homogeneous soil, so for non-homogeneous soils the ultimate point bearing capacity q pu may be calculated using the following relationship, that is qc not plus q C 1 by 2 plus qc 2, this whole divide by 2.

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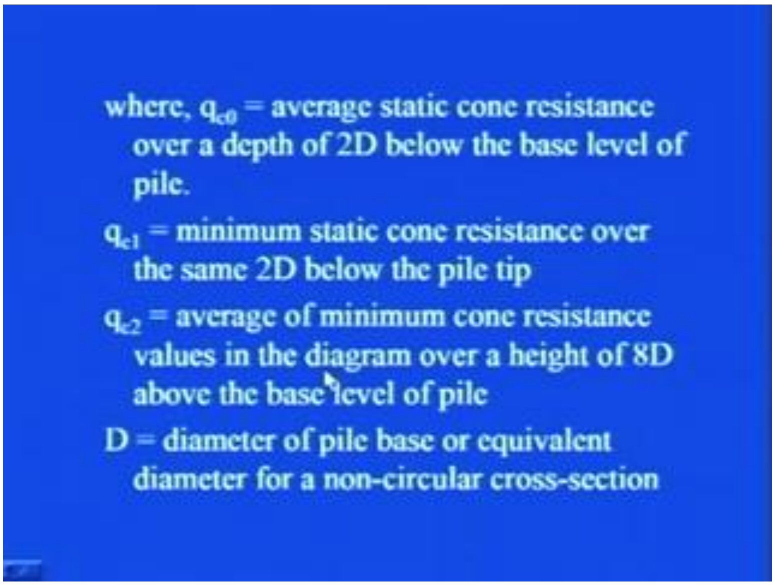

Now, what is qc 0 qc 1 and qc 2, let us try to see that q c 0 is average static cone resistance over a depth of 2 D below the base level of the pile. So, wherever the tip of the pile is resting, you take the depth of 2 D below that, so whatever is the average static cone penetration resistance over that particular depth that is qc 0.

Then, qc 1 is minimum static cone resistance over the same 2 D below the pile tip that is the minimum 1, that you will be taking here qc 0 was average one in this case it is minimum 1. Then, qc 2 is average of minimum cone resistance values in the diagram over a height of 8 D above the base of pile.

So, above the base of the pile that is 8 times diameter of the pile, whatever is the average of minimum values? So, whatever is the minimum value that you will be getting at all particular depth, you take the average of that and that value will be qc 2, where this D is the diameter of the pile base or equivalent diameter for non-circular cross-section.

In case the pile is circular or say rectangular in cross-section then you have to find out the equivalent diameter in case of non-circular cross-section and use that particular value for getting this qc 0 qc 1 and qc 2 D, remaining the same, whether it is diameter or the equivalent diameter.

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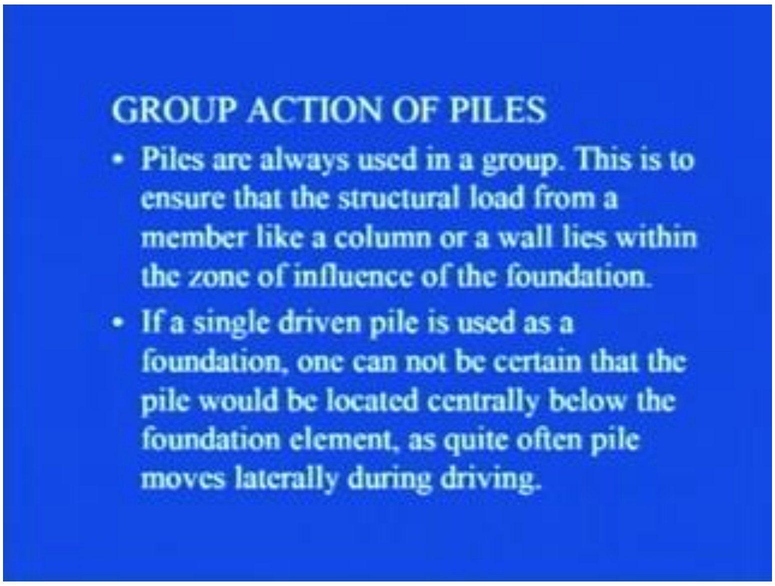

So till now, we were talking of one single pile that is how we would get the load carrying capacity of one particular single pile. And then, when the when I started with this particular topic I told you that usually this single pile is never provided below a kind of below any foundation.

So, let us try to see that, how this group action of piles come into picture, how it is being analyzed as far as settlement and all other things are concerned.

So, let us see some of the salient features of group action of piles. The piles are always used in a group this is to ensure that the structural load from a member like a column or a wall lies within the zone of influence of the foundation. So, they are always used in a group if one single pile is being used, then what are the different problems.

That if a single driven pile is used as a foundation, one cannot be certain that the pile would be located centrally below the foundation element as quite often pile moves laterally during driving. So, in case let us say only one pile is there below the foundation, in that case the centre of gravity of the pile must concede with the load which is coming from the super structure.

So, in case if they are not matching then there will be altogether problem, because some eccentricity will be there and that will cause the movement and which will result into bending of the pile and so the failure of the same. Therefore to avoid this kind of situation, never a single pile is provided below a foundation, because usually what happens is, while installing the pile it moves laterally it is never vertical.

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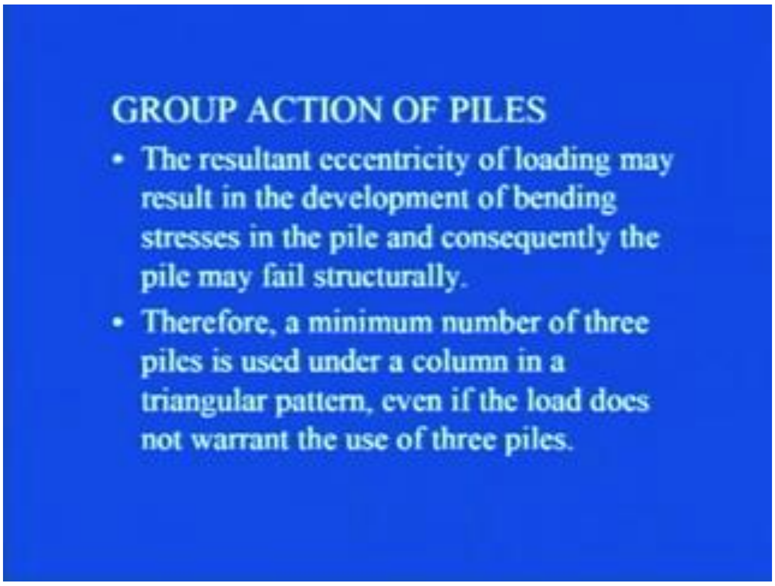

So, the resultant eccentricity of loading may result in the development of bending stresses in the pile and consequently the pile may fail structurally.

So, as I told you that the any eccentricity in between the loading and the cg of the pile it will cause bending stresses in the pile and subsequently the structural failure of the pile. Therefore a minimum number of three piles is used under a column in a triangular fashion even if the load does not warrant the use of three piles.

Let us, say that 100 kilo Newton or may be even higher, let us say that 250 kilo Newton is the load carrying capacity of a pile. And, whatever is the load which is coming from the super its structure is 200 kilo Newton only.

So, there is no need as far as loading point of view is concerned, there is no need to go for more than one pile. But, from this particular consideration that there should not be any eccentricity present there in the foundation system three piles are provided.

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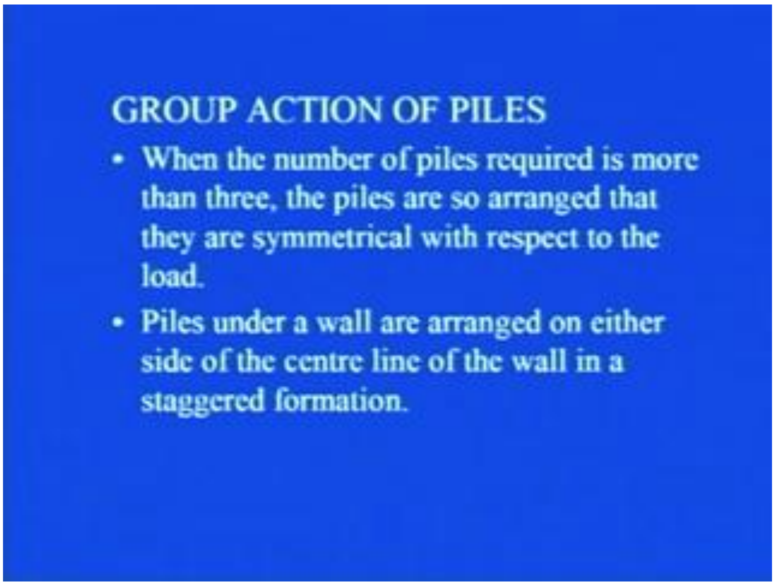

When the number of piles required is more than 3, the piles are so arranged that they are symmetrical with respect to the load, as I told you that there should not be any eccentricity between the loading and the cg of the pile.

So, let us say that your requirement is that you have to go for larger number of piles, then also this thing should be always keep in your mind that whatever is the arrangement of the pile. It should be such that it should be symmetric and it should be such that the it is cg must concede with the cg of the load which is coming from the super its structure to avoid any development of any kind of eccentricity.

Then, piles under wall are arranged on either side of the centre line of a wall in a staggered formation. The wall will be following a particular straight line, so if this is this is let us say that this is a straight line.

So, the piles which will be provided they will be like this way on either side of that particular straight line. Because, then only the arrangement of the pile that the cg of the arrangement of that particular pile will be able to concede the line loading which will be coming from the wall.

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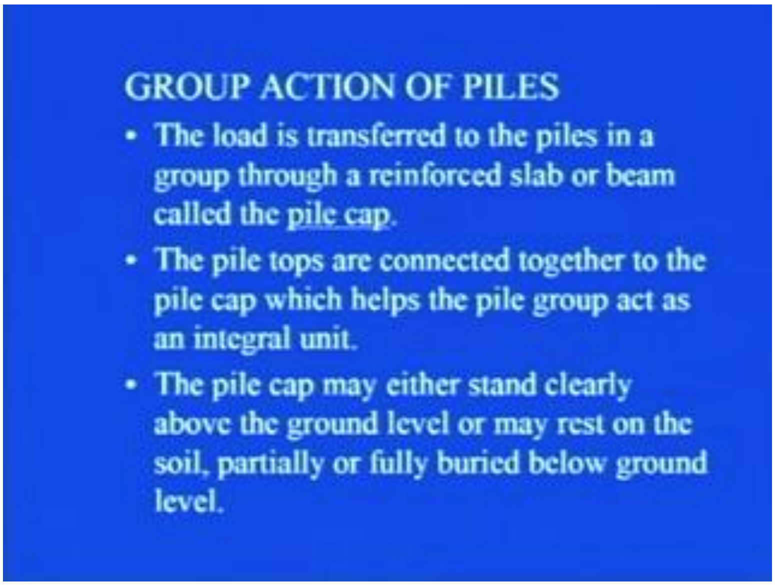

The load is transferred to the piles in a group through a reinforced slab or beam called the pile cap. It is not that as I showed you, when I was sharing some of the pictures that I took from one particular site, that it is not that the piles they are acting separate, separate unit they all of them have to be acting or resisting the load as one particular unit, that is what we call as group action of the pile. So, to combine all those piles, so that load is being transferred to them uniformly some beam or slab is provided on top of that which is called as pile cap.

The pile tops are connected together to the pile cap which helps the pile group act as an integral unit. You see as I explained you that let us say at one particular location 20 numbers of piles are there it is not that those 20 number of piles will be behaving as 20 units. They have to behave as 1 unit only.

Because, whatever is the load which is coming from the super its structure, they it has to be shared by all the piles uniformly or in whatever manner it has been designed for. So, for that particular reason, all the pile tops are connected together using the pile cap.

So, the pile cap may either stand clearly above the ground level or may rest on the soil or partially or fully buried below the ground level. So, this pile cap it can be above the ground it has no contact with the soil. It can be in contact with the soil just placed on the top of the soil or it can be partially buried and partially above the soil.

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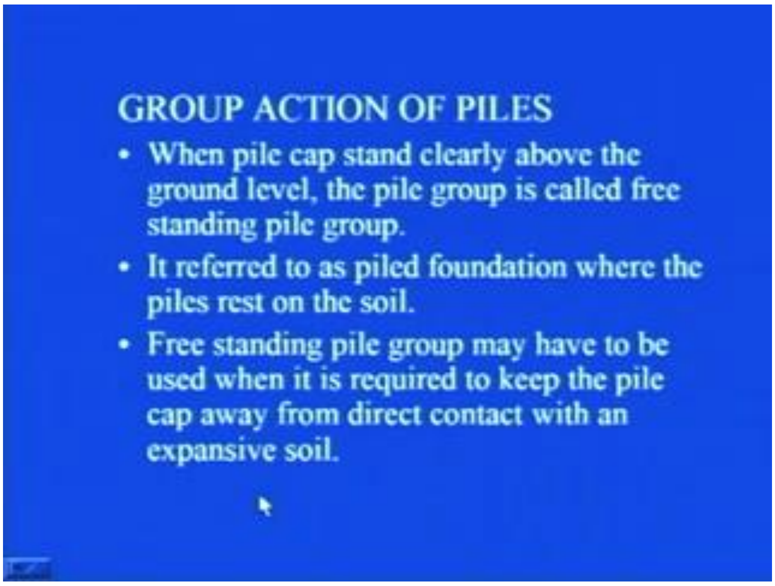

What are the various cases that you will see in the subsequent slides that, in which case this can stand clearly above the ground level. So, when the pile cap is stand clearly above the ground level the pile cap is called free standing pile group.

You must be wondering that, in what case it can be used, you just imagine a case of pile foundation for river abutment, what will happen that, due to the flow of the water the soil above that pile one will get scoured. So, what will happen, the pile cap will not be in contact with the soil below that, so in that case that particular group will be called as free standing pile group.

It is referred to as piled foundation where the piles rest on the soil. So, in this case this is just pile foundation where only piles are in contact with the soil not the pile cap.

Free standing pile group may have to be used when it is required to keep the pile cap away from direct contact with an expansive soil. So, as I told you that the sample of bridge abutment, this is again another one that in case of expansive soil, where you need to keeps this pile cap separate from the soil, there this kind of pile group can be used.

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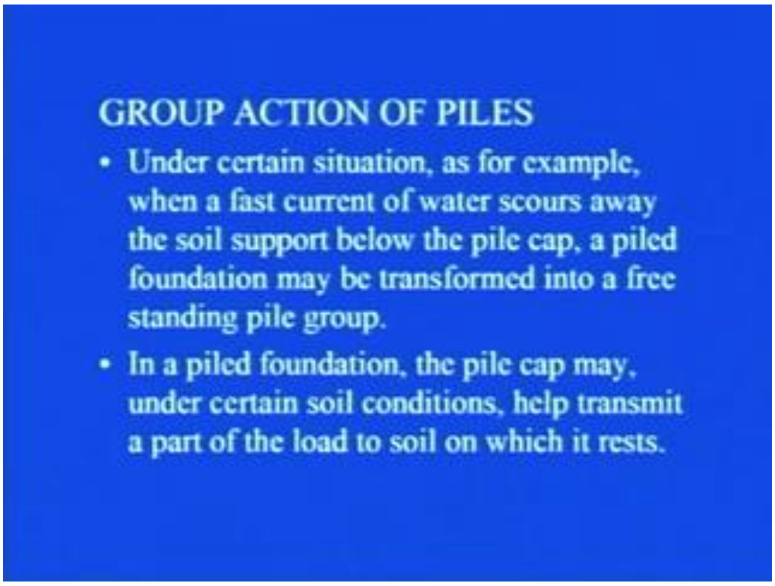

Under certain situation as for example, when a fast current of water scours away the soil support below the pile cap, a pile foundation may be transformed into a free standing pile group. So, as I told that in case of river bridge, at bridge abutment, the flow of the water it scours away the soil which is in contact with the pile draft. And in that case, the pile foundation it will be transformed into a pile standing free standing pile group.

In a piled foundation, the pile cap may under certain soil condition help transmit a part of load to soil on which it rests. So, this pile cap although it connects the all the piles together to help in uniform distribution of the load which is coming from the super its structure along with that function it can help transmitting a part of load to the soil on which it is resting. So, some of the part of the load will be getting transferred to the soil along with the pile.

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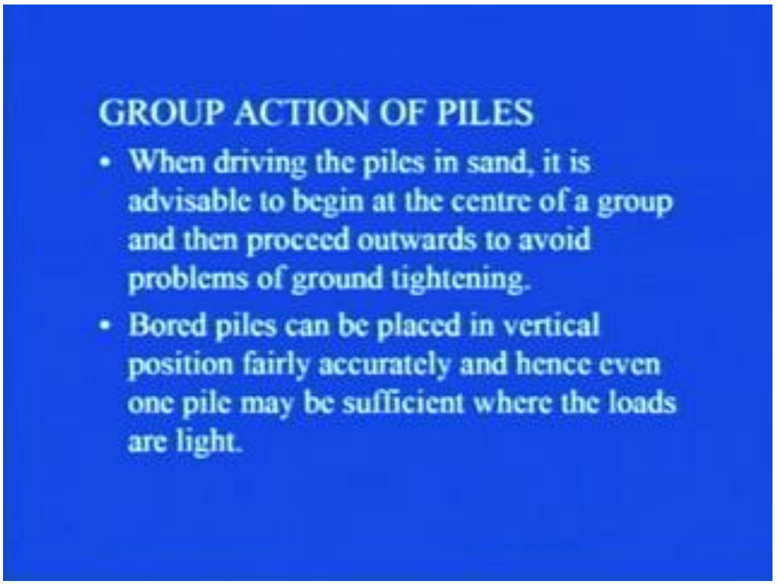

When driving the piles in sand, it is as advisable to begin at the centre of the group and then proceed towards to avoid the problem of ground tightening. As, you know that when you drive a pile in sand, what exactly happens, that during the driving process the sand around that particular pile it gets compacted.

So, in case if you or let us say in case if you first install the pile outwards, what will happen, the area which is their, towards the inward of that particular area will get densified. So, that is what is called the ground tightening and when you will be providing the pile towards I mean in the inward area.

Then, because this ground tightening has already taken place you will face lot of difficulty in driving the pile. So, it is always advisable that when you are driving the pile in sand you must go from inward to outward that is first you must install the piles towards at the centre of the group and then you can go outwards.

However, what happens in case of bored piles, these piles can be placed in vertical position fairly accurately and hence even one pile may be sufficient where the loads are light. So in case of driven piles, you are using hammering or vibration techniques to drive the pile and in that process it may happen that the pile can move laterally. So, that can cause the development of eccentricity.

However in case of bored piles, you create an excavation or avoid or a bore hole in the soil and then you do the concreting or the drive the pile inside that particular bore hole. So, when you are driving the bore hole, it is very much under your control that, what is the alignment of that particular bore hole? So in case of bored piles, the vertical drive driving of the pile or vertical installation of the pile is very much possible and therefore, one pile can be used.

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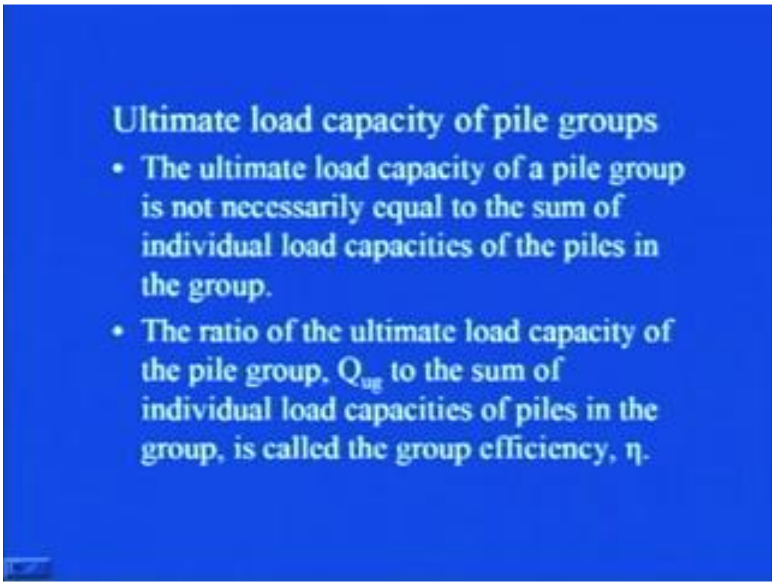

Now, let us try to see that, we have already seen that there were four methods to find out ultimate load carrying capacity of single pile. Now, how we can find out the ultimate load capacity of pile groups.

So, in case of this ultimate pile load capacity of a pile group is not necessarily equal to the sum of individual load capacities of the piles in the group. Let us say that, there are hundred piles in a group and each pile is having ultimate load carrying capacity of say 100 kilo Newton that does not mean that the group of 100 piles will have the ultimate load carrying capacity is equal to 100 into 100 kilo Newton.

It is not so, how you can find out why exactly it is not so let us try to see in subsequent slides. The ratio of the ultimate load capacity of the pile group that is Q ug g stands for group to the sum of individual load capacities of piles. In the group is called the group efficiency; that means, the eta is equal to Q ug divided by Q u, where Q ug is the ultimate load capacity of pile group Q u is the ultimate load carrying capacity of single pile.

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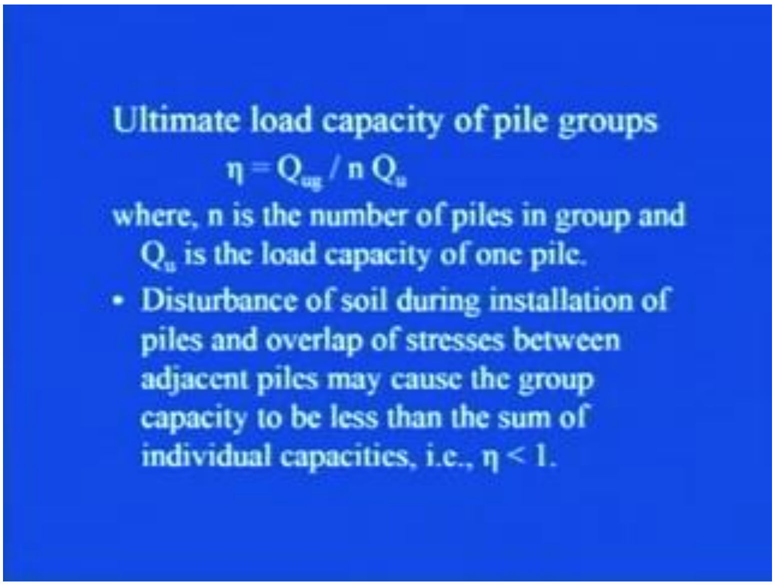

You see here, that is Q ug is eta is equal to Q ug by n Q u, Q ug is n is the number of piles in the group Q ug is load capacity of group and Q u is the load capacity of one pile.

Then, disturbance of soil during installation of pile and over lap of stresses between adjacent piles may cause the group capacity to be less than the sum of individual capacities that is they can cause this value of eta to be less than one.

See when the, you are driving the pile or installing the pile there is the disturbance in the surrounding soil and then further if the two piles are quiet close there can be overlap of the stresses which are being developed. So, that can be the reason for which that efficiency can be less than one.

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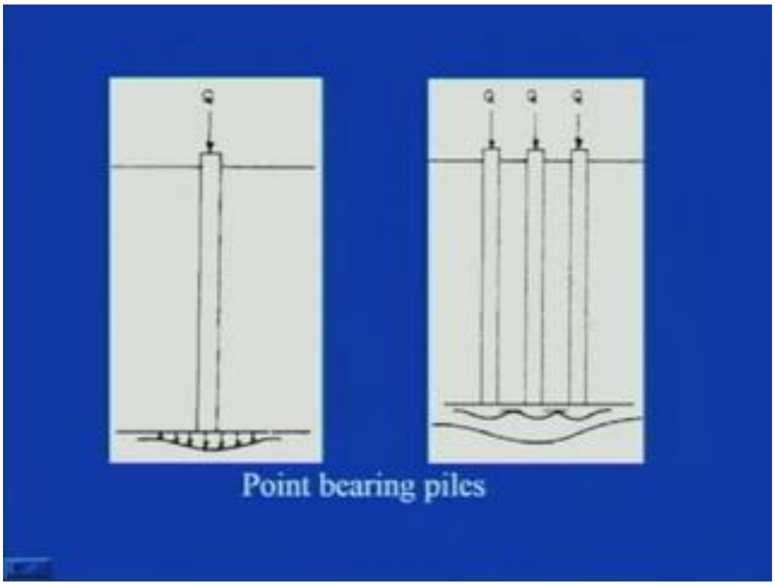

You can see here in this particular case that these are the two cases of one for single pile another for group of piles. As far as point bearing piles are concerned. I am not considering any skin friction resistance, so this is a single pile subjected to a compressive load of q. This point bearing is getting resisted in this particular fashion.

It is distribution is in this particular fashion, however in case of group of files for this particular pile this is a group of this is a type that it will be getting distributed. However, for the second one it will be like this third one it is like this. So, you are seeing that here in this area there is some overlap of the stresses which are developed due to the point bearing. So, resulting these three that is the total one will be like this.

So, now I hope that you can understand and appreciate that, why the ultimate capacity of a group. Let us say only of three piles cannot be equal to the sum of the piles individual load carrying capacity, so you see due to this overlap.

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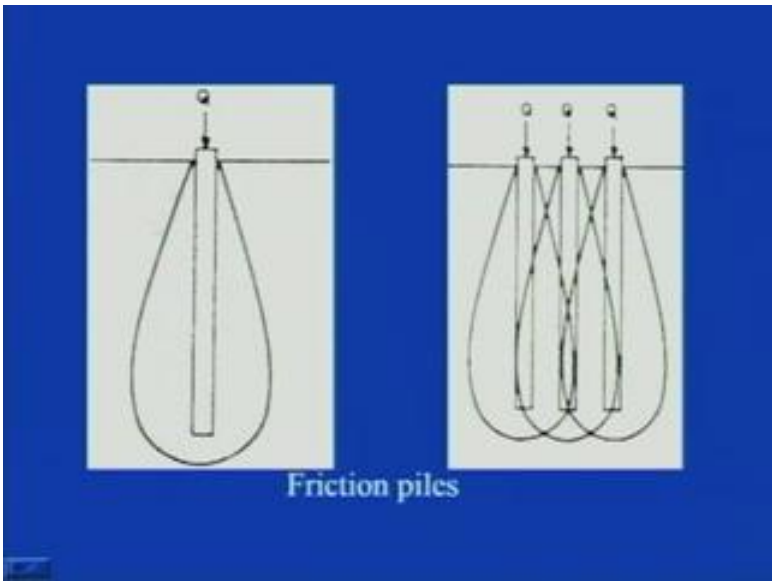

In case of friction pile, this is how the friction bulb has been found, in case of the single pile. However in case of group of piles you can see, that for this particular pile it is this particular bulb for this one this particular bulb and if you see only these two this much is the area which is overlapping.

So, combined effect of these will be this much area may be, because for the third one if you see then this is the over lapping. So, the over lapping area of all the three is this much and then you can have a look that, how these are getting affected,when the piles are adjacent to each other they are close to each other that these are the reasons why this eta takes a value less than one.

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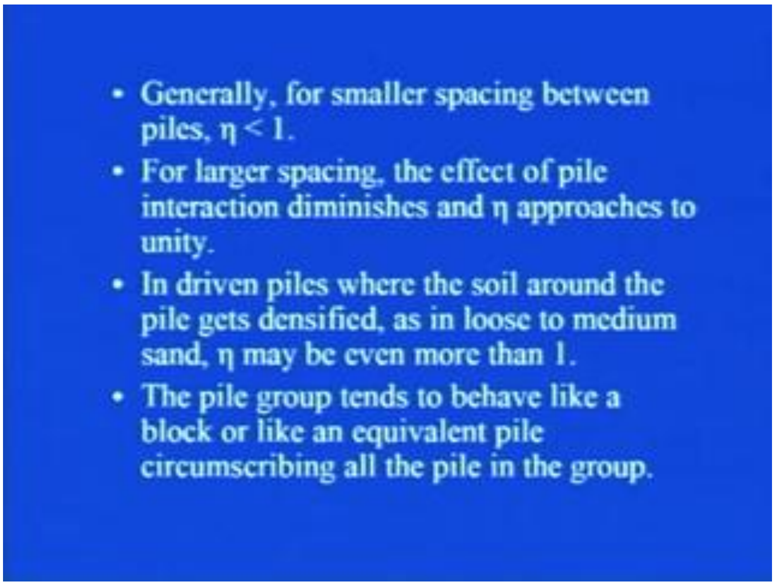

Generally, for a smaller spacing between the piles eta is less than one, I just now showed you with the help of two figures that how this eta is coming out to be less than one.

For larger spacing, the effect of pile interaction diminishes and eta approaches to unity. See, if the large spacing is there you will have sufficient space in between the bulbs may be in case of point bearing as well as in case of skin friction in between for the two adjacent piles. And therefore, the capacity of the group of the pile will become equal to the capacity of 1 pile multiplied by the number of piles which are provided in that particular group. So, in that case your eta can approach to unity.

In driven piles, where the soil around the pile get densified as in loose to medium sand eta may be even more than one. Because, what happens is that, when the soil is getting compacted or dense, in the process of driving the pile that is in case of driven piles, what happens is that, whatever is the load from the super its structure is coming.

When that particular load gets transferred to the pile it is not that only it is getting transferred to the pile. As I told you, that the pile cap helps transferring that load to the soil also. So, when the soil got densified; obviously, that will also share some part of the load and that is that is how that eta value will become more than one.

The pile group tends to behave like a block or like an equivalent pile some circumscribing all the piles in a group. So, usually this pile group it acts like a block or if you take the extreme piles and if you circumscribe particular area, then that will be behaving as one particular pile in this particular case.

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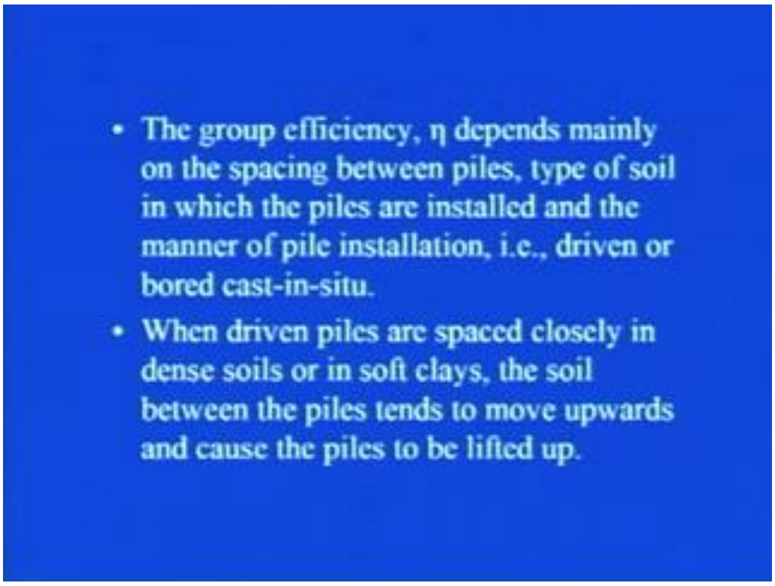

The group efficiency eta, depends mainly on the spacing between piles type of soil in which the piles are installed and the manner of pile installation that is whether it is driven or bored cast- in-situ pile as you have seen that we have already discussed all these aspects one by one in detail.

So, when driven piles are spaced closely in dense soil or in soft clays the soil between the pile tends to move upwards and cause the piles to be lifted up. When the piles are quite close to each other and then the load when it comes while driving the pile it the soil between the piles has the tendency to move upward.

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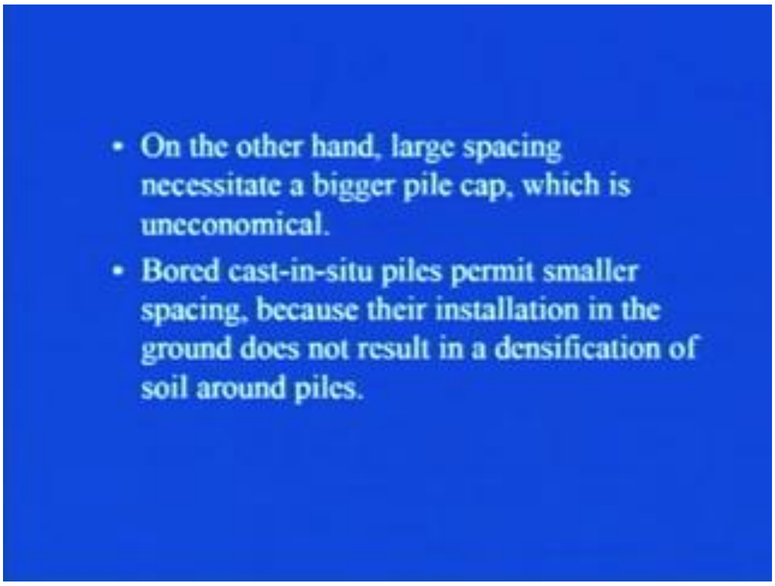

On the other hand, the large spacing necessitate a bigger pile cap which is uneconomical. Bored cast-in-situ piles permit smaller spacing because their installation in the ground does not result in the densification of soil around the piles.

So, you see that how this spacing has become so much important as far as group action of the piles is concerned. So, what are they various aspects of deciding upon that, what should be the spacing of the piles depending on, what exactly is the type of the soil are the type of the pile that, you are going to install, what is the method of the installation of that particular pile, all these aspects we will be studying in detail in the subsequent class.

So, today in this particular lecture, we saw that various aspects of modified Haley formula which was dynamic pile formula. And then, we discussed the various correlations which have been developed over. So, many years by different research workers and engineers took correlate, the allowable load carrying capacity of the pile to the test data which is available from either a static cone penetration test data or standard penetration test.

Then, they all have some or other limitation again I will again repeat that you have to be very careful about the units when you are using these correlations. After that, we proceeded with the group action of the pile and in that one we saw that how you can estimate or what exactly is the mechanism of estimating the ultimate load carrying capacity of group of piles.

In that one, we saw that the efficiency of a pile group which is the ratio of the ultimate load carrying capacity of pile group and number of piles times the ultimate capacity of one single pile, how it can be less than one equal to one or greater than one.

Then, we saw that this efficiency of a pile group depends significantly on the pile spacing and this pile spacing depends on that what exactly is the type of pile that you are using, what is the method of installation, what is the diameter of and the size and shape of the pile. So, further what are the various recommendations by IS code that we will be discussing in the next class along with some of the examples.

Thank you.